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Hull, Arthur N.

Monterey, California. Naval Postgraduate School

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# A METHOD OF FORECASTING THE FORMATION OF 500-MILLIBAR BLOCKS USING STATISTICAL PARAMETERS

ARTHUR N. HULL

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# A METHOD OF FORECASTING THE FORMATION OF 500-MILLIBAR BLOCKS USING STATISTICAL PARAMETERS.

* * * * * * * *

Arthur N. Hull

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by

Arthur N. Hull

This work is accepted as fulfilling
the thesis requirements for the degree of
MASTER OF SCIENCE
IN
METEOROLOGY
from the
United States Naval Postgraduate School

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Submitted in partial fulfillment of
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METEOROLOGY

United States Naval Postgraduate School
Monterey, California

1961

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| A | Station Identifier |
| B | Station Identifier |
| C | Station Identifier |
| C.G. | Center of Gravity |
| c | Relative confidence value |
| D | Station Identifier |
| $E_1$ | First predictor |
| $E_2$ | Second predictor |
| F-DAY | Formation day of block |
| F-6 | Six days prior to block formation (similarily for F-5, etc.) |
| Q | Station identifier |
| R | Station identifier |
| S | Station identifier |
| SSW | Selfridge, Stevenson, and Wood, co-authors of reference [6] |
| $\sigma$ | Standard deviation |
| T | Station identifier |
| U | Station identifier |
| V | Station identifier |
| W | Station identifier |
| x, y | General terms and subscripts used in formulae development. |

| | |
|---|---|
| $Z$ | 500-mb actual height |
| $\overline{Z}$ | Long-term mean 500-mb height |
| $z$ | 500-mb height anomaly |
| $\overline{z}$ | mean 500-mb height anomaly |
| Subscripts | |
| Letters | Refer to station identifiers |
| Numbers | Refer to days prior to block formation |

Example: $Z_{A6}$ - 500-mb actual height at station A on F-6.

$z_{A6}$ - 500-mb height anomaly at station A on F-6.

Later in the thesis this notation is shortened to simply $A_6$.

$A_{54}$ - 500-mb height-anomaly tendency at station A between F-5 and F-4

# ABSTRACT

An investigation is made of the statistical properties of blocks at the 500-mb level along the latitude belt 50-55N covering 180 degrees of longitude including the block area. From the results obtained a method of computing a 72-hour forecast of block formation is developed.

The author is deeply indebted to Professor Frank L. Martin for his advice and guidance during the progress of this investigation. Grateful acknowledgement is also due Professor Richard C. Campbell for his invaluable aid in programming the statistical routine used in the CDC-1604 computer.

## 1. Introduction

Extended forecasting by statistical means is a field of meteorology relatively untapped yet showing vast promise of success. The most fruitful attempts appear to be in the field of weather-typing as used by Elliott [2] et al, and weather typing by orthogonal functions as used by Malone [4, chapter 28] et al The one major shortcoming of weather-typing, however, lies in the difficulty of predicting the type to follow.

The most persistent weather type in any one area is the block. Definitions of blocks vary widely but all definitions require a relatively stationary flow pattern for periods ranging from three to more than ten days. Predictibility of the formation of a block in any one sector would thus aid weather-typing considerably. It is the purpose of this investigation, therefore, to devise a method of forecasting block-formations at 500 mb using statistical parameters.

Rex [5] thoroughly investigated blocking patterns in the lower and middle troposphere, and correlated anomalies of temperature and precipitation with marked success. In his definition of a block, the flow pattern was required to maintain its identity for a period of at least ten days. Selfridge, Stevenson, and Wood [6], hereafter referred to as SSW, based their findings on the definition used by Serebreny [7,8] that a block must remain in the sector of origin for a

period of at least three days. In this study, all the characteristics of block types described by SSW and Serebreny have been utilized. Blocking-type boundaries are as defined by SSW and Serebreny. This investigation covers the period from six days before the formation of a block, F-6 day , until F-DAY, which is the day the block is actually within the defined type boundaries.

Because of the availability of ocean stations and land stations both upwind and downwind, the Sub-Icelandic block was chosen for use as development data in this investigation. The formation area for the Sub-Icelandic block is contained within the area 50-65N and 10-30W.

## 2. Data Collection

Eleven stations were selected within the boundaries 50-55N and 10E to 177W in order adequately to cover the area in which it was believed indications of block formation would appear. The stations selected are as indicated in Fig. 1 below.

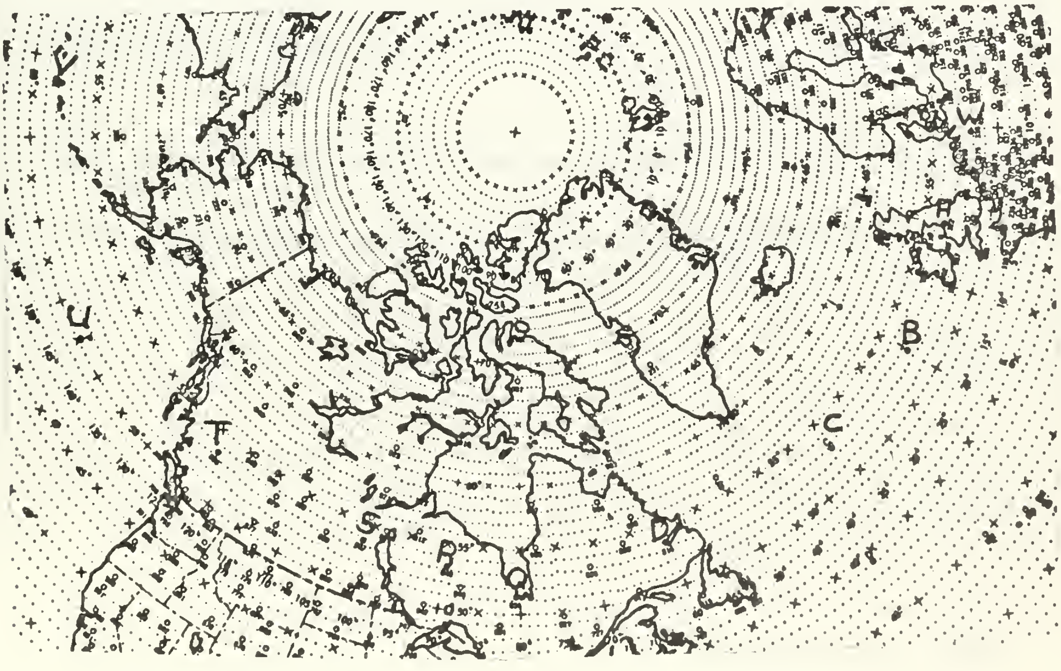

Fig. 1. Weather plotting map illustrating stations and station indicators used in development.

For all fifteen winter cases of Sub-Icelandic blocks listed in the calendar of types in SSW, the actual 500-mb data were collected for the period ranging from F-6 through F-DAY from the Historical Weather Map Series [10].

The mean monthly contours from "Normal 500-mb Charts for the Northern Hemisphere" [11] were used to obtain the 500-mb mean height for each station in the month of each block. In some cases, linear extrapolation was used for computing the means.

From the observed heights and their means, height anomalies were computed. These data were transferred to IBM punch cards. Linear correlation computations between height anomalies were then produced for all eleven stations taken two at a time, and for each day prior to and including F-3.

## 3. Method of Computation

All computations were made using the CDC-1604 computer. Data were programmed using the formulae listed below:

$$Z_X - \overline{Z}_X = z_X \,, \qquad (1)$$

$$Z_Y - \overline{Z}_Y = z_Y \,, \qquad (2)$$

$$\overline{z}_X = \frac{1}{n} \sum z_X \,, \qquad (3)$$

$$\bar{z}_Y = \frac{1}{n} \sum z_Y \,, \tag{4}$$

$$\sigma_{z_x}^2 = \frac{1}{n} \sum ( z_x - \bar{z}_x )^2, \tag{5}$$

$$\sigma_{z_Y}^2 = \frac{1}{n} \sum ( z_Y - \bar{z}_Y )^2, \tag{6}$$

$$r_{xY} = \frac{\sum ( z_x - \bar{z}_x )( z_Y - \bar{z}_Y )}{n \, \sigma_{z_x} \, \sigma_{z_Y}} \,. \tag{7}$$

In the set of formulae above, n=15 is the sample size, $z_x$ is the height anomaly at station x for the specified day before block formation. $r_{xy}$ is a correlation between $z_x$ and $z_y$. In most cases correlations for the same day were preferred (Table 1); correlations involving different time lags were also performed (Table 2). In addition, 24-hour height-change values were correlated across the entire network of stations (Table 3). In general, these gave many excellent significant correlations but were not considered to be as useful predictors as the previous two types of correlation coefficients.

In all computations, heights as measured, and anomalies as computed are in tens of feet.

## 4. Evaluation of Computations

From Hoel [1], assuming that the long-term theoretical correlation of height anomalies between stations is equal to zero, and that the height anomalies are normally distributed, an actual value for the correlation coefficient (based on 15 independent cases) whose magnitude is equal to or greater than 0.473 is significant at the 95% level of

belief. The criteria for the selection of prediction stations were that, in all cases, the correlation coefficients between stations must be greater than 0.473 in magnitude and, furthermore, there must be at least three stations which are mutually and significantly correlated. Trial predictor stations were selected from the list of correlations shown in Table 1.

Since it had been previously determined that a 72-hour forecast would be developed, the correlations for F-2, F-1, and F-DAY were not used in the development.

Graphs of height anomalies were next drawn for each pair of significantly correlated stations associated with block formation. These graphs are shown in Figs. 3 through 9.

Using a table of random numbers [12], fifteen cases of non-blocks were randomly selected and height anomalies for these cases were plotted on the appropriate graphs for the corresponding day. The regression line for block cases only was plotted on each graph.

A discriminant analysis of the type used by Miller [3] was next performed on each graph. It was discovered, as expected, that the correlation between a station the the block area and one immediately adjacent was uniformly positive, and in no way discriminated between blocks and non-blocks. Of 17 graphs tested, 10 were rejected as having no forecast value.

On the graphs which were retained, subjective analysis of the type used by Thompson [9] was conducted. This consisted of drawing rel-

ative confidence isolines numbered from 0 to 5 on each graph. The "5" isoline encircles clusters of block cases near the regression line, and the "0" line is near the axis of the perpendicular to the regression line. Essentially the areas within the "0" and "5" lines test the hypotheses to reject or accept block formation respectively, while the remaining areas delineate the intermediate critical region No block case was permitted to correspond to a relative confidence value of less than three. This in effect assigned spacial weights in the critical region.

The critical region was further tested in the following manner: (1) it is assumed that the events leading up to block formation are sequential in nature and therefore to be equally weighted; and (2) the relative confidence value from each graph is summed for each day, thus assigning equal weight for each graph The graphs which display these relative confidence isolines are shown in Figs. 3 through 9.

It was noted that some blocking cases which had high relative confidence values on F-6 and F-5 had low values on F-3. Since no combination of pairs of stations gave good correlations on F-4, it was necessary to use a discriminant analysis between F-5 and F-4. Accordingly, the relative confidence values for the four graphs on F-6 and F-5 were summed and termed the first predictor ($E_1$). Since each day was to be equally weighted, the second predictor ($E_2$) was formed by summing twice the relative confidence value of the F-4 graph plus the sum of the F-3 graphs. These two predictors for non-block and

Table 1. Table of significant height-anomaly correlations with no lag.

| Anomalies Correlated | F-6 | F-5 | F-4 | F-3 | F-2 | F-1 | F-DAY |
|---|---|---|---|---|---|---|---|
| W A | 0.47 | 0.68 | 0.56- | 0.79 | 0.87 | 0.74 | 0.77 |
| A B | 0.66 | 0.55 | 0.60 | 0.55 | 0.52 |  |  |
| B C | 0.68 | 0.47 |  | 0.52 |  | 0.53 |  |
| C D |  |  |  |  | 0.49 |  |  |
| D Q |  | 0.49 |  |  |  |  |  |
| Q R | 0.79 | 0.69 |  | 0.72 | 0.79 | 0.74 | 0.75 |
| R S | 0.69 | 0.85 | 0.63 | 0.86 | 0.77 | 0.82 | 0.53 |
| S T |  |  |  | 0.56 |  | 0.49 |  |
| T U |  | 0.55 |  |  |  |  |  |
| U V |  |  |  |  |  |  |  |
| W B |  |  |  |  |  |  |  |
| A C |  |  |  |  |  |  |  |
| B D |  |  |  | -0.51 |  |  |  |
| C Q | -0.47 | -0.63* | -0.49 |  |  |  |  |
| D R |  |  |  |  |  | 0.66 |  |
| Q S |  | 0.58 |  | 0.58 |  |  |  |
| R T |  |  |  |  |  |  |  |
| S U | -0.55 | -0.66 |  |  |  |  |  |
| T V |  |  |  | -0.62 | -0.58 | -0.57 |  |
| W C |  |  |  |  |  |  |  |

* - Denotes those correlations used in the forecast procedure

Table 1 (continued)

| Anomalies Correlated | F-6 | F-5 | F-4 | F-3 | F-2 | F-1 | F-DAY |
|---|---|---|---|---|---|---|---|
| A D | | | | | | | -0.47 |
| B Q | | | -0.57 | | -0.49 | | |
| C R | | -0.59* | | | | | |
| D S | | | | | | 0.48 | |
| Q T | | | | | | | |
| R U | | -0.48 | | | | | |
| S V | | | | -0.57 | -0.65 | -0.48 | |
| W D | -0.52 | | | | | | |
| A Q | | | | | | | |
| B R | | | | -0.62 | -0.57 | -0.49 | |
| C S | | | | | | | |
| D T | -0.49 | | | | | | |
| Q U | | | -0.49 | | | | |
| R V | | | | | -0.62 | | |
| W Q | | | | | | | |
| A R | | | | -0.58 | -0.50 | | |
| B S | | | | -0.65 | | | |
| C T | | | | 0.47 | | | |
| D U | | | | | | | |
| Q V | | | | | | | |

* - Denotes those correlations used in the forecast procedure

Table 1 (continued)

| Anomalies Correlated | F-6 | F-5 | F-4 | F-3 | F-2 | F-1 | F-DAY |
|---|---|---|---|---|---|---|---|
| W R | | | | | | | |
| A S | | | | -0 59* | | | -0.53 |
| B T | | | | | | | |
| C U | | | | | | | |
| D V | | | | | | | |
| W S | | | | | | | |
| A T | | | | -0.49* | | | |
| B U | | | | | | | |
| C V | | | | | | | |
| W T | | | | -0.50 | | | -0.48 |
| A U | | | | | | | |
| B V | -0.70* | -0.67 | | | | | |
| W U | | | | | | | |
| A V | -0.48* | | | | | | |
| W V | | | | | | | |

* - Denotes those correlations used in the forecast procedure.

Table 2. Table of significant height-anomaly correlations with various lags.

| Anomalies Correlated | Correlation Coefficient |
|---|---|
| $W_2T_3$ | -0.54 |
| $A_3R_2$ | -0.58 |
| $A_3S_2$ | -0.51 |
| $S_2T_3$ | 0.65 |
| $A_3T_2$ | -0.49 |
| $C_1V_6$ | -0.63 |
| $A_3D_5$ | -0.47 |
| $W_6A_5$ | 0.69 |
| $A_5D_2$ | -0.55 |
| $C_5Q_4$ | -0.83* |
| $C_5V_2$ | 0.55 |
| $D_3D_2$ | 0.50 |
| $D_3Q_4$ | 0.55 |
| $R_4S_5$ | 0.49 |
| $S_5V_2$ | -0.71 |
| $U_3V_2$ | 0.52 |

* - Denotes those correlations used in the forecast procedure

Table 3. Table of significant correlations of 24-hour height tendencies with various lags.

| Anomalies Correlated | | Correlation Coefficient |
|---|---|---|
| $B_{10}$ | $Q_{54}$ | 0.90 |
| $B_{10}$ | $C_{32}$ | -0.50 |
| $C_{32}$ | $Q_{54}$ | -0.66 |
| $W_{54}$ | $D_{43}$ | -0.60 |
| $W_{54}$ | $S_{32}$ | -0.60 |
| $B_{21}$ | $C_{32}$ | 0.72 |
| $B_{10}$ | $D_{43}$ | 0.58 |
| $D_{43}$ | $Q_{54}$ | 0.54 |
| $Q_{54}$ | $S_{32}$ | 0.63 |
| $T_{54}$ | $U_{32}$ | -0.51 |

block cases were next plotted (Fig. 10). The centers of gravity for block cases and non-block cases were next determined and a line joining these centers of gravity was constructed. The standard deviation for non-blocks was next determined and a distance along the line connecting the two centers of gravity of 1.64 standard deviations from the center of gravity of non-blocks was marked. A line perpendicular to the line joining the centers of gravity was drawn through this point. Assuming the predictor values are normally distributed, non-blocks lying on the block side of this line have less than a 10% chance of occurrence.

## 5. The Forecast Procedure

As stated earlier, it was assumed that the mechanisms or the series of events correlated are sequential in the case of the Sub-Icelandic block. For the forecast procedure, it was further assumed that this series of sequential correlations holds true for any block and that only a shift in base line is necessary for computation. Therefore, a base line as close as possible to the one used in the Sub-Icelandic block computations has been developed. For simplicity, the latitude line of 50N was selected as the base line. Station locations are as indicated in Fig. 2 below.

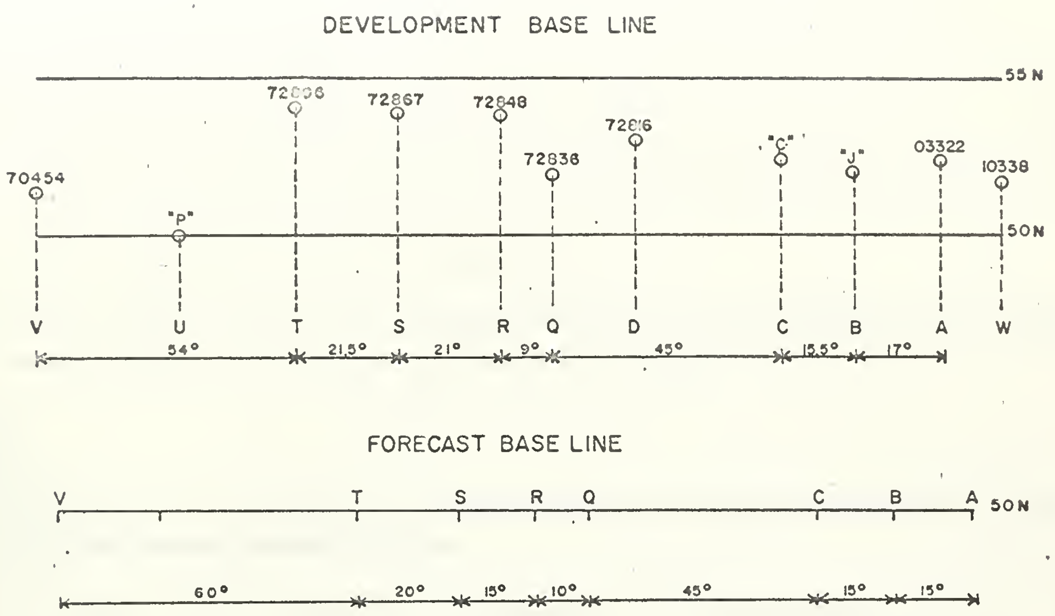

Fig. 2. Comparison of spacing of station indicators used in both development phase and forecast phase.

For any type of block, the longitude of the center of the block-type area as defined by Serebreny [5,6] and SSW is used as the longitude of station B. The other stations are located east or west of this point as indicated by the "forecast base line" of Fig. 2.

Using the same station identifiers as in the development stage but oriented relative to the new base line, height anomalies are computed for stations A, B, and V for F-6 and stations C, Q, and R for F-5. Relative confidence values are determined from the appropriate graphs and summed for the first predictor,

$$E_1 = c(A_6V_6) + c(B_6V_6) + c(C_5Q_5) + c(C_5R_5). \qquad (8)$$

Height anomalies are then computed for station Q on F-4, and for stations A, S, and T on F-3. Relative confidence values are thenobtained from the appropriate graphs and summed according to the formula be-

low to obtain the second predictor

$$E_2 = 2c(C_5Q_4) + c(A_3S_3) + c(A_3T_3). \tag{9}$$

Test data were thus obtained for each of 15 winter cases of blocks and non-blocks in the following areas:

1) three cases each of Bering Sea-Western Alaska blocks, Sub-Aleutian blocks, and Scandanavian-Baltic blocks;

and

2) two cases each of Sub-Icelandic blocks, England-North Sea blocks, and Western Canada blocks.

The results of these computations are indicated in Fig. 10. The data for these computations are compiled in Appendices III and IV.

## 6. Results and Conclusions

From the space correlations in SSW, the expected frequency of block days in all four sectors which they investigated is 903 block days out of a possible 2168 days. Of these block days, 209 were initial formation days. The remaining block days were rejected from the total, since only initial block days and non-block days were used in testing. The climatological expectency of block formations thus is 0.142 per day. The climatological expectency of non-block days is then considered to be $1-0.142 = 0.858$. From the sample summarized in Table 4, a forecast accuracy of 87 percent and a skill score, based on the climatological expectencies, of 0.73 were obtained.

Table 4. Contingency table of forecast results.

|  | Observed |  |
|---|---|---|
| Forecast | Blocks | Non-blocks |
| Blocks | 13 | 2 |
| Non-blocks | 2 | 13 |

In conclusion, although few cases were used to derive this forecast precedure, the results indicate that sequential correlations do exist, both upwind and downwind during block formation, that can be utilized to make a 72-hour forecast. It is believed that 1) by increasing the base line to a full 360 degree arc around the latitude belt of 50N, 2) by decreasing the station-to-station interval to a constant 15 degrees of longitude, and 3) by studying many more cases, that sequential correlations will be found to exist that will correctly forecast not only block formation but also block dissipation. It is also within the realm of possibility that the forecast can be extended to a period of greater than 72 hours. It is further believed that such forecasting methods as presented herein may be of great value in determining empirical relationships to be entered as corrections or modifications to the results of numerical prognostic maps as currently being issued.

| | |
|---|---|
| Figs. 3 - 9 | Graphs of relative confidence isolines. |
| Fig. 10 | The forecast graph |

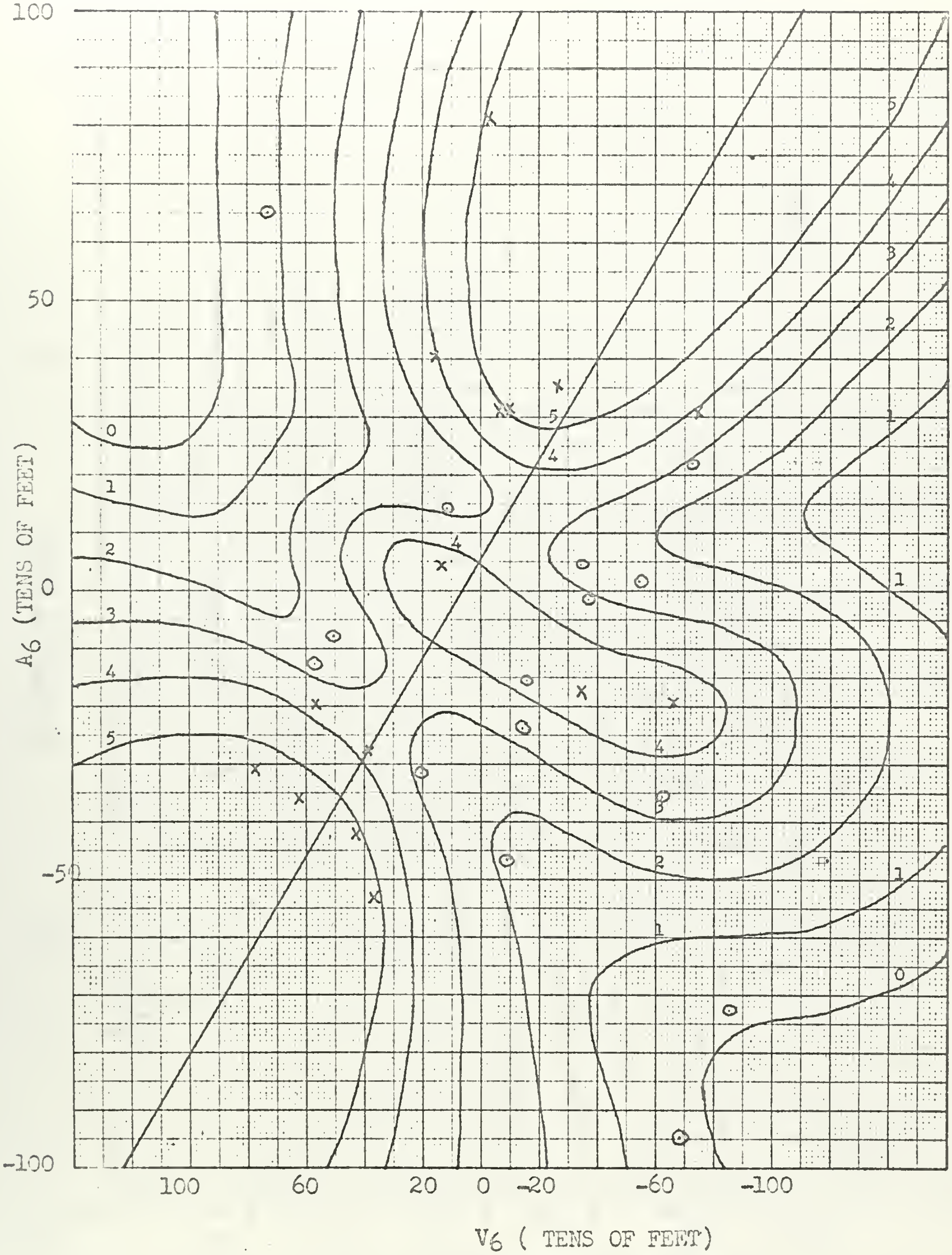

Fig. 3 Graph of relative confidence values for $A_6V_6$.

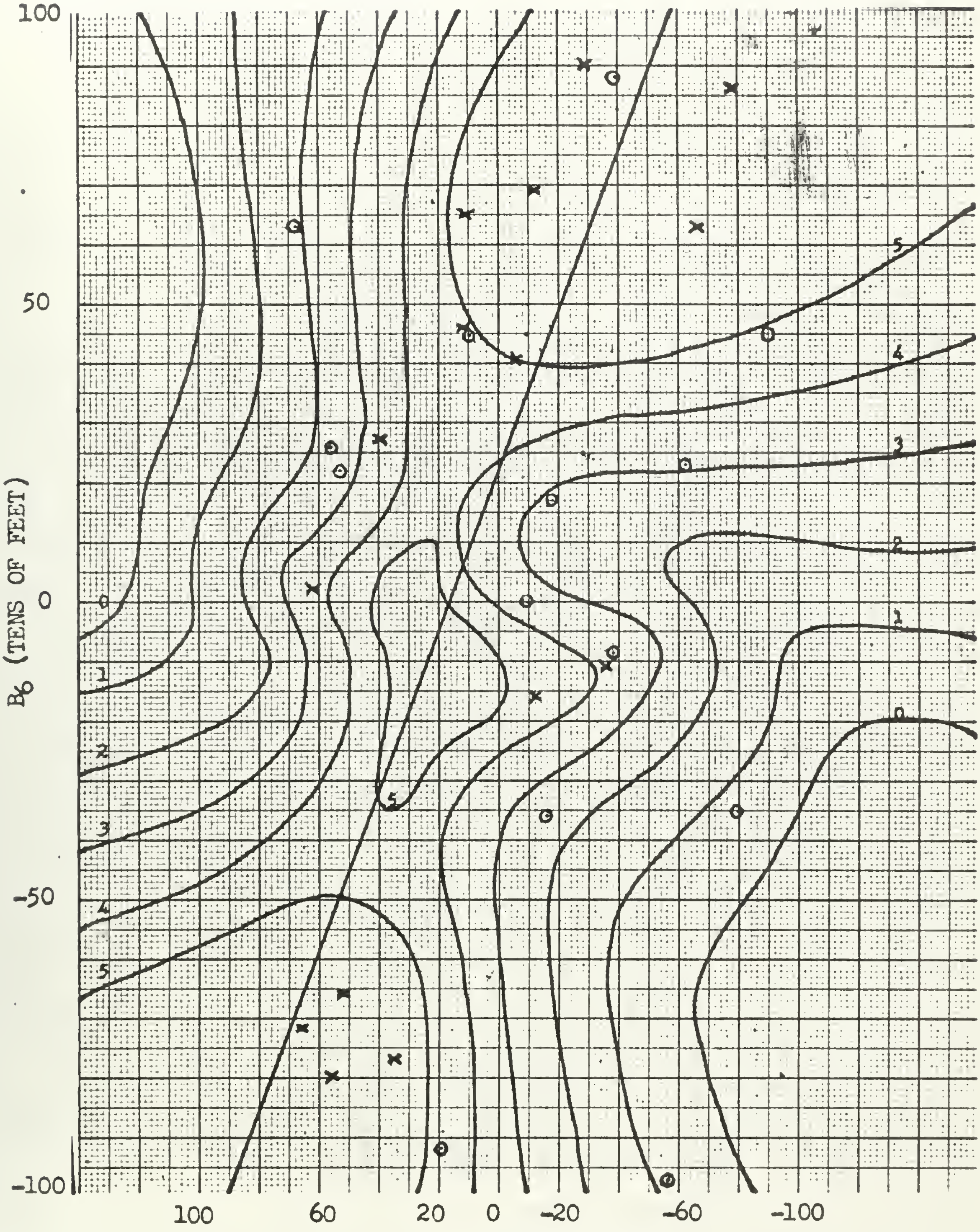

Fig. 4 Graph of relative confidence values for $B_6V_6$.

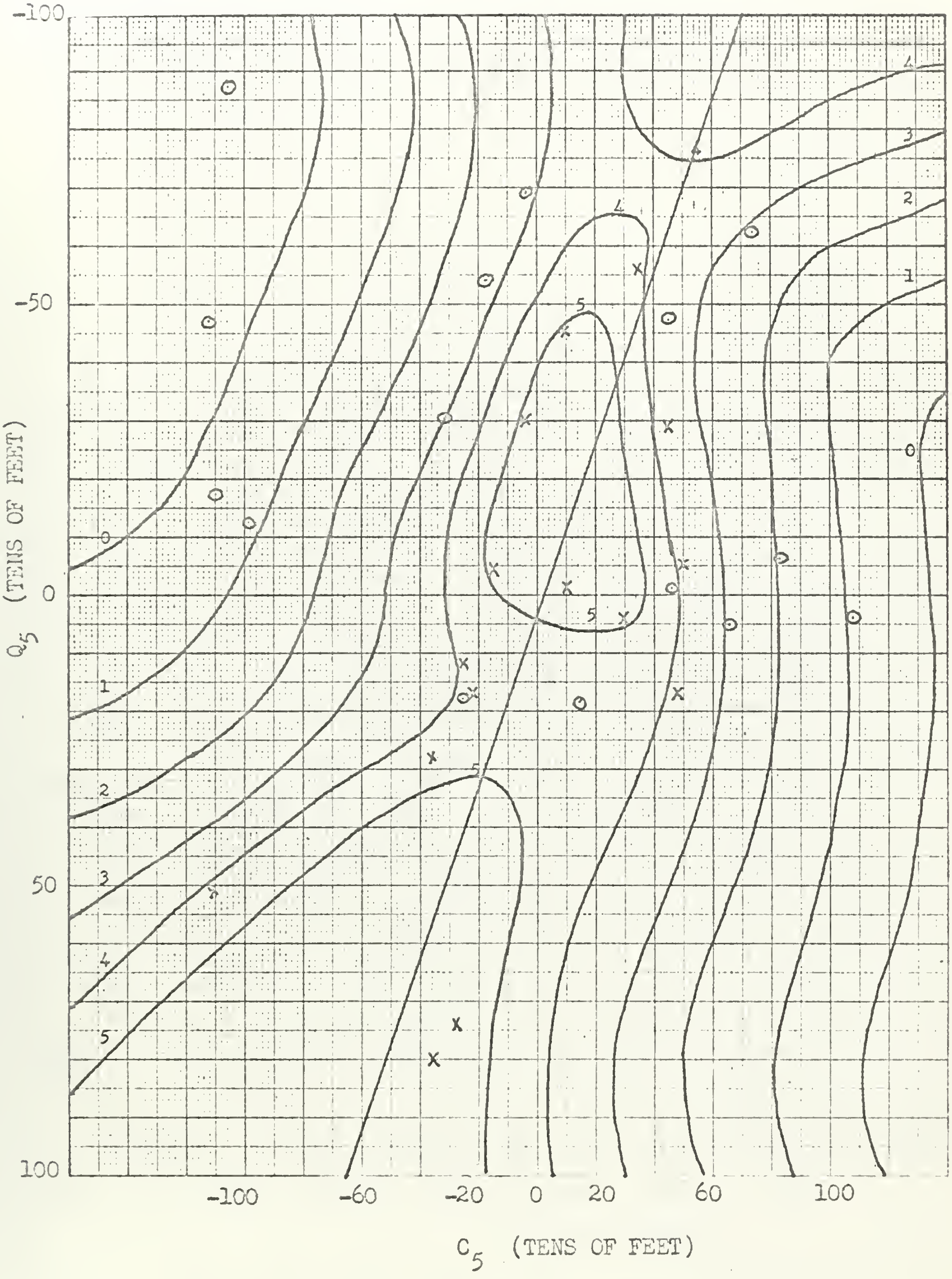

Fig. 5 Graph of relative confidence values for $C_5Q_5$.

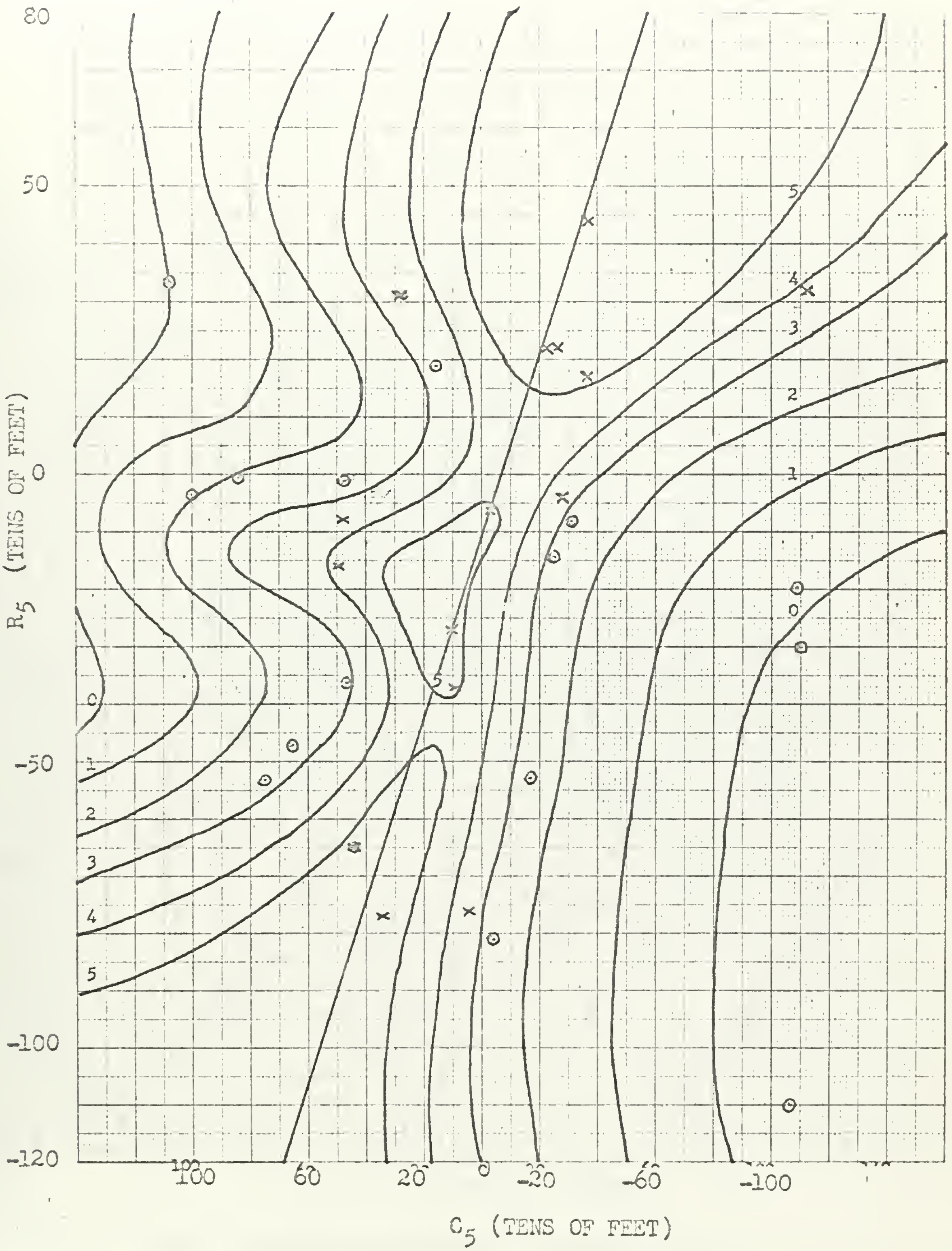

Fig. 6. Graph of relative confidence for $C_5R_5$.

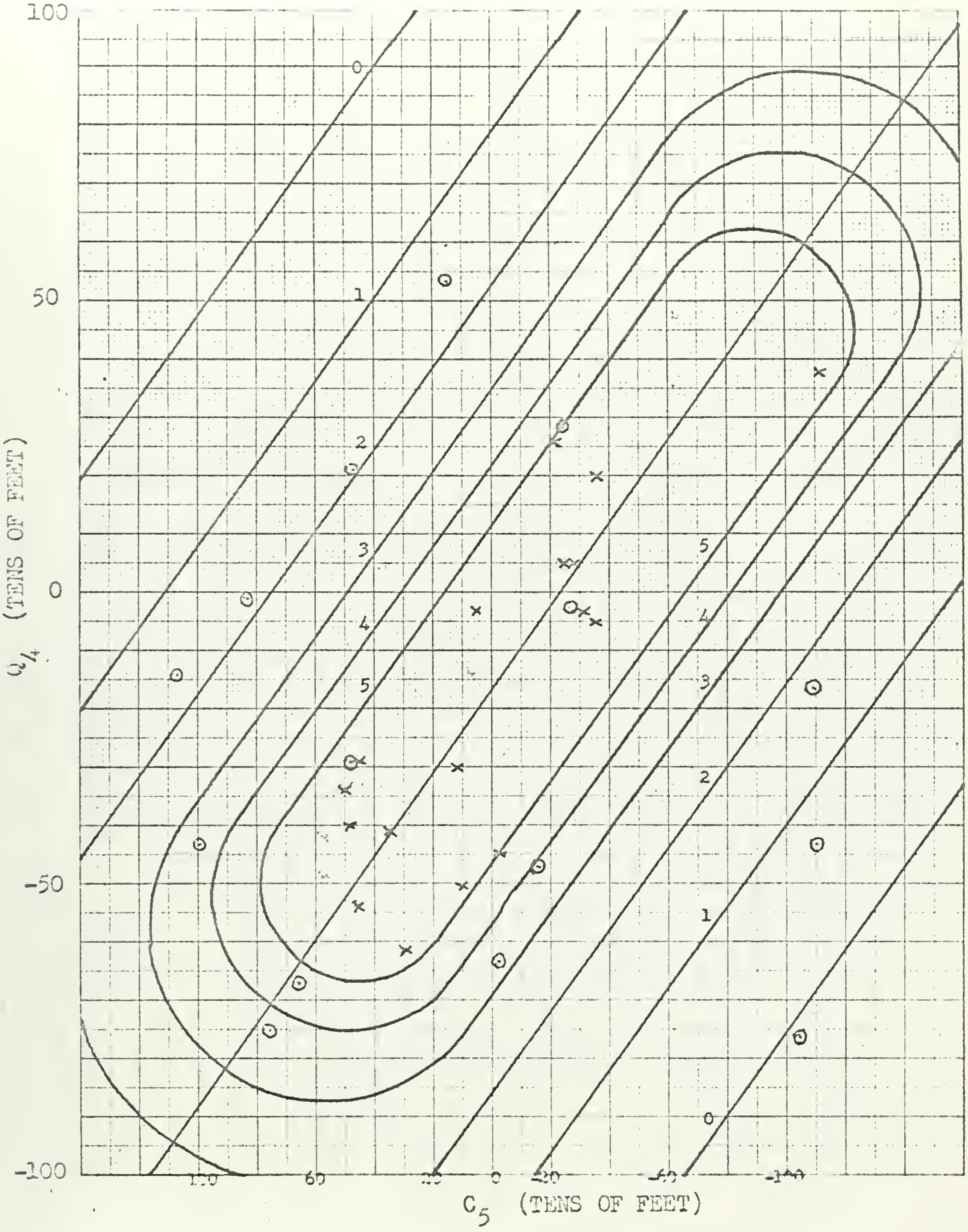

Fig. 7 Graph of relative confidence values for $C_5Q_4$.

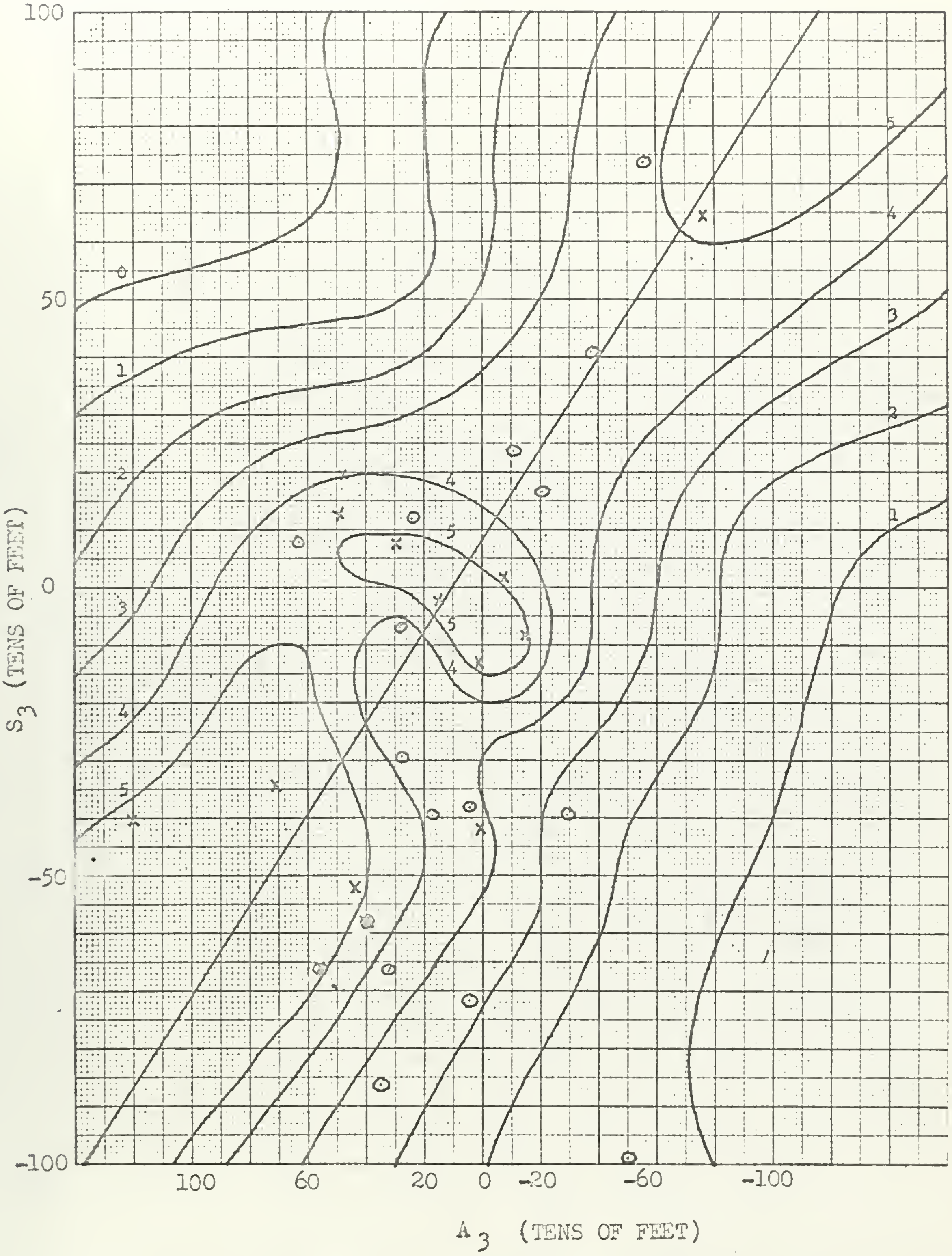

Fig. 8 Graph of relative confidence values for $A_3S_3$.

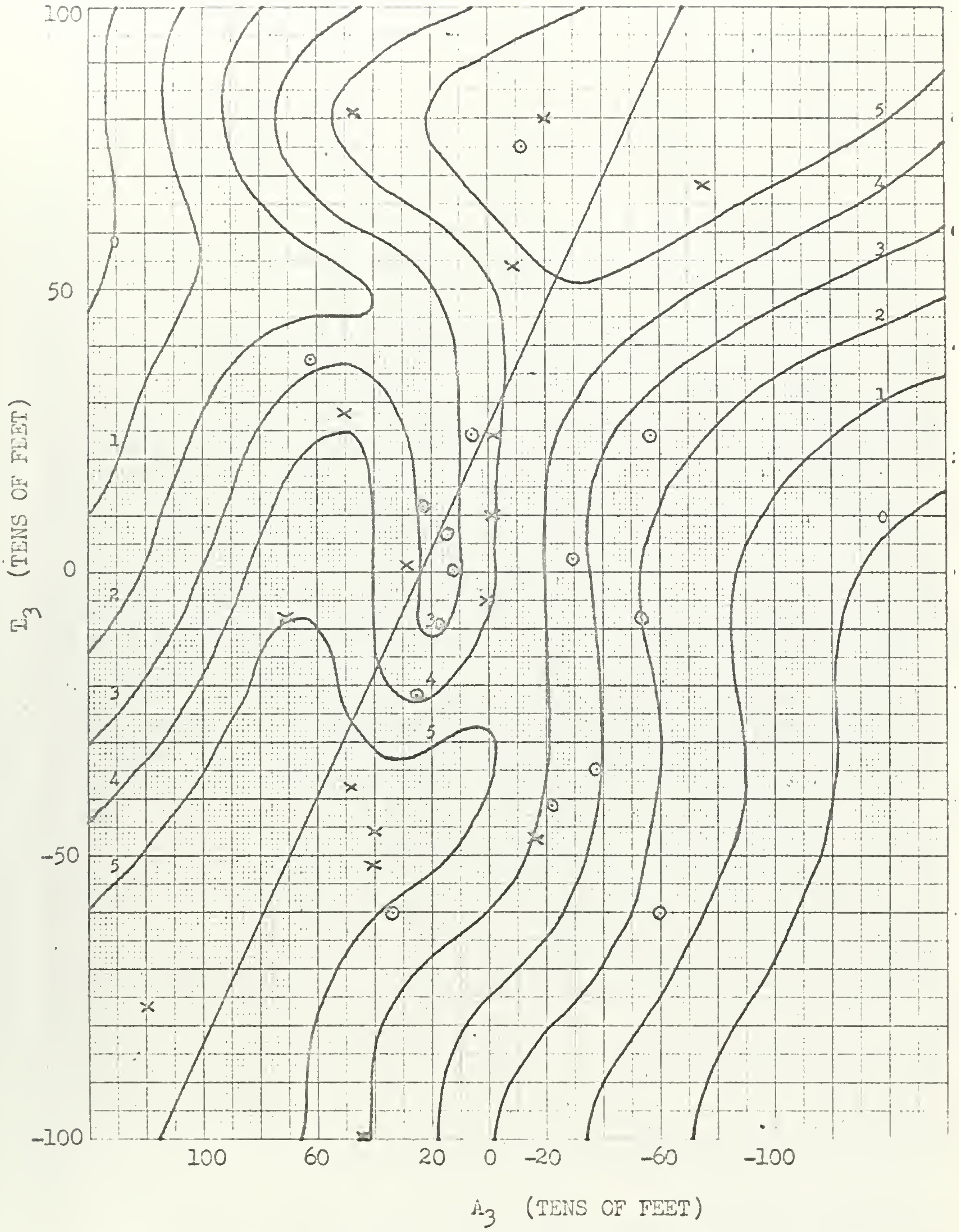

Fig. 9 Graph of relative confidence values for $A_3T_3$.

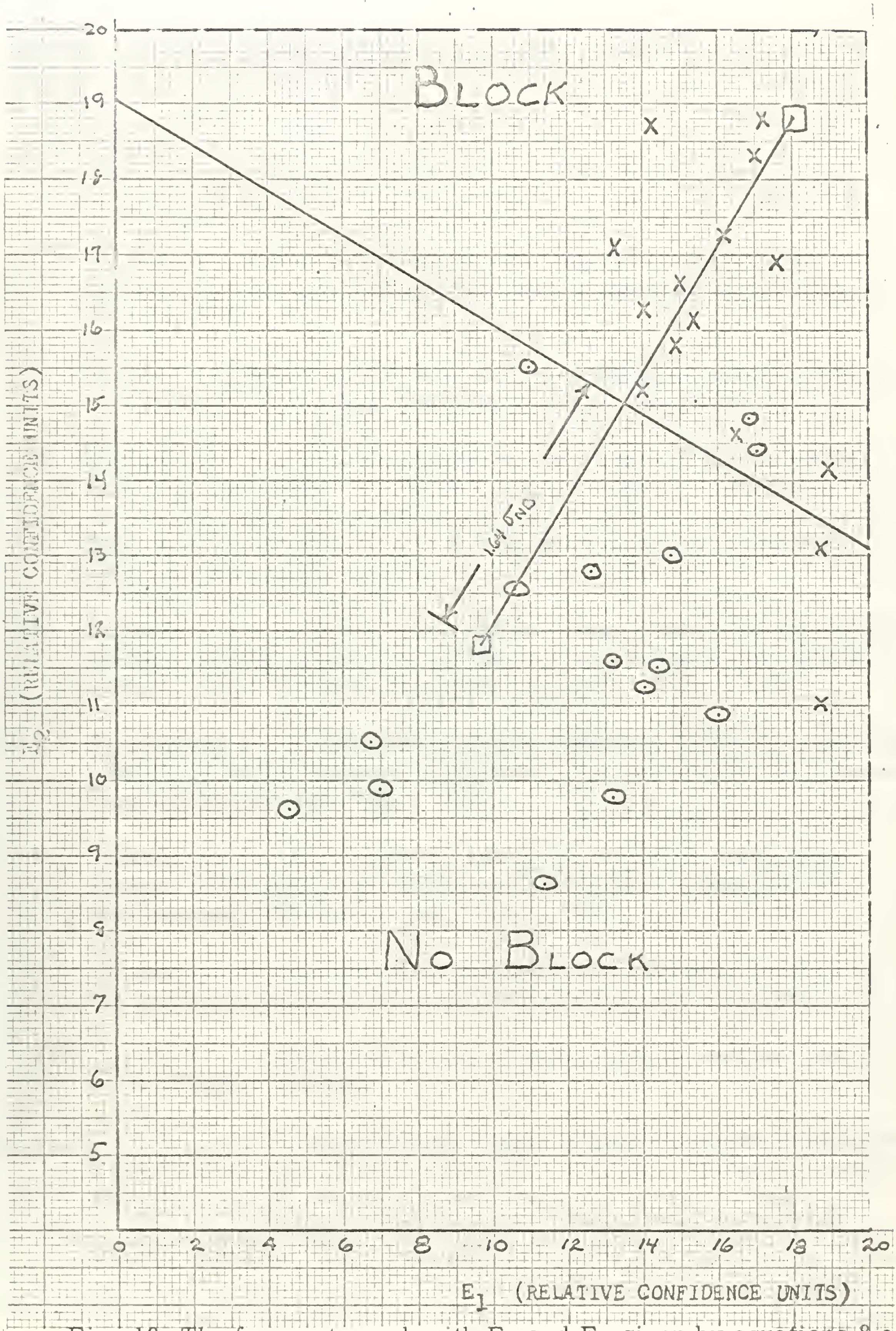

Fig. 10 The forecast graph with $E_1$ and $E_2$ given by equations 8 and 9.

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# APPENDIX I

## Height anomalies for 15 cases of Sub-Icelandic blocks

(Values given in tens of feet)

| Case# | $A_6$ | $B_6$ | $V_6$ | $C_5$ | $Q_5$ | $R_5$ | $Q_4$ | $A_3$ | $S_3$ | $T_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -25 | +62 | -66 | -25 | +12 | +22 | + 5 | -76 | +65 | +68 |
| 2 | -36 | + 2 | +62 | + 5 | - 4 | -76 | - 3 | +43 | -52 | -109 |
| 3 | -47 | -66 | +43 | - 3 | -30 | - 6 | -45 | - 2 | +15 | +24 |
| 4 | -31 | -72 | +77 | +11 | -45 | -27 | -30 | +29 | + 8 | + 1 |
| 5 | +81 | +40 | - 4 | +10 | - 1 | -37 | -50 | +40 | -58 | -46 |
| 6 | +35 | +90 | -28 | +35 | -56 | -77 | -41 | +51 | -66 | +28 |
| 7 | -20 | -80 | +57 | -22 | +17 | +22 | +26 | - 8 | + 2 | +54 |
| 8 | -28 | +27 | +39 | -36 | +28 | +17 | - 5 | +48 | +20 | +81 |
| 9 | + 4 | +46 | +12 | +50 | - 5 | -16 | -34 | ± 0 | -41 | - 5 |
| 10 | -53 | -77 | +36 | -28 | +74 | - 4 | + 5 | -16 | - 8 | -47 |
| 11 | +32 | -16 | -12 | -36 | +80 | +44 | +20 | +49 | +13 | -38 |
| 12 | +40 | +65 | +15 | +48 | +17 | - 8 | -40 | +71 | -34 | - 8 |
| 13 | +30 | +86 | -77 | +45 | -29 | -65 | -54 | - 1 | -14 | +10 |
| 14 | +31 | +69 | -11 | +29 | + 4 | +26 | -61 | +120 | -40 | -77 |
| 15 | -18 | -11 | -35 | -112 | +51 | +32 | +38 | +41 | - 5 | -52 |

# APPENDIX II

## Height anomalies for 15 cases of non-blocks in Sub-Icelandic area

| Case # | $A_6$ | $B_6$ | $V_6$ | $C_5$ | $Q_5$ | $R_5$ | $Q_4$ | $A_3$ | $S_3$ | $T_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | +14 | +45 | −11 | +47 | −1 | −1 | +21 | +32 | −66 | −59 |
| 2 | −37 | +23 | −62 | +45 | −47 | −36 | −29 | −53 | −139 | −8 |
| 3 | −8 | +21 | +51 | −17 | −54 | −53 | −47 | +35 | −86 | −60 |
| 4 | +22 | −35 | −79 | −110 | −17 | −20 | −16 | +15 | −39 | +6 |
| 5 | −2 | +88 | −38 | +107 | +4 | +34 | −14 | +63 | +8 | +37 |
| 6 | +65 | +63 | +68 | +65 | +5 | −47 | −67 | ±0 | −71 | +12 |
| 7 | −24 | −36 | −15 | −25 | +18 | −14 | +29 | −56 | +74 | +24 |
| 8 | −13 | +26 | +57 | +75 | −62 | −53 | −75 | −29 | −39 | +2 |
| 9 | −47 | ±0 | −9 | +83 | −6 | ±0 | −1 | −11 | +24 | +75 |
| 10 | +4 | −9 | −35 | −3 | −69 | −81 | −63 | −38 | +41 | −35 |
| 11 | −73 | +45 | −86 | +99 | −12 | −3 | −43 | +26 | −6 | +11 |
| 12 | −16 | +17 | −17 | −32 | −30 | −8 | −3 | +27 | −29 | −22 |
| 13 | −95 | −48 | −68 | +15 | +19 | +19 | +54 | +20 | +11 | −10 |
| 14 | +1 | −97 | −55 | −111 | −47 | −30 | −43 | −21 | +17 | −41 |
| 15 | −32 | −92 | +20 | −106 | −87 | −110 | −76 | +4 | −41 | +24 |

# APPENDIX III

## Test data; height anomalies for 15 block cases miscellaneous areas

| Case # | Block Type |
|---|---|
| 1. | Bering Sea-Western Alaska |
| 2. | Sub-Aleutian |
| 3. | Sub-Aleutian |
| 4. | Bering Sea-Western Alaska |
| 5. | England-North Sea |
| 6. | Scandanavian-Baltic |
| 7. | Western Canada |
| 8. | Western Canada |
| 9. | England-North Sea |
| 10. | Bering Sea-Western Alaska |
| 11. | Scandanavian-Baltic |
| 12. | Sub-Icelandic |
| 13. | Scandanavian-Baltic |
| 14. | Sub-Icelandic |
| 15. | Sub-Aleutian |

# F-6

| Case # | Date | $Z_{A_6}$ | $\overline{Z}_{A_6}$ | $z$ | $Z_{B_6}$ | $\overline{Z}_{B_6}$ | $z_{B_6}$ | $Z_{V_6}$ | $\overline{Z}_{V_6}$ | $z_{V_6}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/5/54 | 692 | 768 | −76 | 761 | 745 | +16 | 795 | 784 | +11 |
| 2. | 2/4/54 | 781 | 779 | +2 | 659 | 764 | −95 | 752 | 770 | −18 |
| 3. | 1/8/57 | 822 | 787 | +35 | 819 | 776 | +43 | 737 | 774 | −37 |
| 4. | 1/13/54 | 834 | 783 | +51 | 830 | 769 | +61 | 710 | 777 | −67 |
| 5. | 2/22/53 | 848 | 779 | +69 | 890 | 802 | +88 | 640 | 758 | −118 |
| 6. | 1/23/56 | 779 | 779 | ± 0 | 798 | 783 | +15 | 675 | 778 | −103 |
| 7. | 2/16/50 | 825 | 753 | +72 | 800 | 780 | +20 | 815 | 780 | +35 |
| 8. | 2/22/57 | 733 | 772 | −39 | 740 | 785 | −45 | 833 | 775 | +58 |
| 9. | 1/16/54 | 770 | 788 | −18 | 818 | 802 | +16 | 840 | 760 | +80 |
| 10. | 3/19/56 | 762 | 770 | −8 | 729 | 749 | −20 | 810 | 793 | +17 |
| 11. | 1/24/57 | 794 | 777 | +17 | 775 | 787 | −12 | 830 | 773 | +57 |
| 12. | 12/3/45 | 758 | 790 | −48 | 805 | 790 | +15 | 783 | 730 | +53 |
| 13. | 1/25/51 | 770 | 773 | −3 | 798 | 778 | +20 | 791 | 781 | +10 |
| 14. | 3/20/57 | 721 | 799 | −78 | 738 | 797 | −59 | 756 | 740 | +16 |
| 15 | 2/12/57 | 840 | 784 | +56 | 824 | 780 | +44 | 780 | 772 | +8 |

# F-5

| Case # | Date | $Z_{C_5}$ | $\overline{Z}_{C_5}$ | $z_{C_5}$ | $Z_{Q_5}$ | $\overline{Z}_{Q_5}$ | $z_{Q_5}$ | $Z_{R_5}$ | $\overline{Z}_{R_5}$ | $z_{R_5}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/6/54 | 688 | 721 | -33 | 740 | 703 | +37 | 749 | 729 | +20 |
| 2. | 2/5/54 | 692 | 742 | -50 | 700 | 690 | +10 | 755 | 701 | +54 |
| 3. | 1/9/57 | 810 | 754 | +56 | 680 | 690 | -10 | 690 | 686 | +4 |
| 4. | 1/14/54 | 799 | 744 | +55 | 668 | 685 | -17 | 715 | 693 | +22 |
| 5. | 2/23/53 | 840 | 802 | +38 | 690 | 729 | -39 | 711 | 719 | -8 |
| 6. | 1/24/56 | 781 | 801 | -20 | 750 | 760 | -10 | 758 | 740 | +15 |
| 7. | 2/17/50 | 781 | 783 | -2 | 768 | 742 | +26 | 698 | 729 | -31 |
| 8. | 2/23/57 | 703 | 780 | -77 | 800 | 742 | +58 | 725 | 708 | +17 |
| 9. | 1/17/54 | 872 | 809 | +63 | 705 | 731 | -26 | 644 | 719 | -75 |
| 10. | 3/20/56 | 729 | 728 | +1 | 769 | 732 | +37 | 700 | 750 | -50 |
| 11. | 1/25/57 | 815 | 804 | +11 | 640 | 748 | -109 | 649 | 730 | -81 |
| 12. | 12/4/45 | 785 | 766 | +19 | 724 | 721 | +3 | 752 | 720 | +32 |
| 13. | 1/26/51 | 770 | 804 | -34 | 857 | 767 | +90 | 846 | 749 | +97 |
| 14. | 3/21/57 | 759 | 776 | -17 | 751 | 751 | ± 0 | 770 | 743 | +27 |
| 15. | 2/13/57 | 762 | 770 | -8 | 699 | 701 | -2 | 716 | 690 | +26 |

F-4

| Case # | Date | $Z_{Q_4}$ | $\overline{Z}_{Q_4}$ | $z_{Q_4}$ |
|---|---|---|---|---|
| 1. | 1/7/54 | 716 | 703 | +13 |
| 2. | 2/6/54 | 680 | 690 | −10 |
| 3. | 1/10/57 | 660 | 690 | −30 |
| 4. | 1/15/54 | 682 | 685 | − 3 |
| 5. | 2/24/53 | 685 | 729 | − 44 |
| 6. | 1/25/56 | 750 | 760 | − 10 |
| 7. | 2/18/50 | 777 | 742 | + 35 |
| 8. | 2/24/57 | 792 | 742 | + 50 |
| 9. | 1/18/54 | 648 | 731 | − 93 |
| 10. | 3/21/56 | 742 | 732 | + 10 |
| 11. | 1/26/57 | 690 | 748 | − 58 |
| 12. | 12/5/45 | 741 | 721 | + 20 |
| 13. | 1/27/51 | 852 | 767 | + 85 |
| 14. | 3/22/57 | 757 | 751 | + 6 |
| 15. | 2/14/57 | 671 | 701 | − 30 |

F-3

| Case # | Date | $Z_{A_3}$ | $\overline{Z}_{A_3}$ | $z_{A_3}$ | $Z_{S_3}$ | $\overline{Z}_{S_3}$ | $z_{S_3}$ | $Z_{T_3}$ | $\overline{Z}_{T_3}$ | $z_{T_3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/8/54 | 710 | 768 | −58 | 760 | 761 | −1 | 804 | 780 | +24 |
| 2. | 2/7/54 | 769 | 779 | −10 | 772 | 733 | +39 | 798 | 768 | +30 |
| 3. | 1/14/57 | 819 | 787 | +32 | 701 | 715 | −14 | 760 | 761 | −1 |
| 4. | 1/16/54 | 841 | 783 | +58 | 723 | 730 | −7 | 731 | 770 | −39 |
| 5. | 2/25/53 | 850 | 779 | +71 | 730 | 730 | ±0 | 750 | 761 | −11 |
| 6. | 1/26/56 | 761 | 779 | −18 | 761 | 718 | +43 | 770 | 728 | +42 |
| 7. | 2/19/50 | 812 | 753 | +59 | 703 | 701 | +2 | 660 | 693 | −33 |
| 8. | 2/25/57 | 809 | 772 | +37 | 715 | 690 | +25 | 690 | 701 | −11 |
| 9. | 1/19/54 | 817 | 788 | +29 | 712 | 721 | −9 | 668 | 753 | −85 |
| 10. | 3/22/56 | 688 | 770 | −82 | 748 | 780 | −32 | 781 | 796 | −15 |
| 11. | 1/27/57 | 804 | 776 | +28 | 639 | 719 | −80 | 690 | 737 | −47 |
| 12. | 12/6/45 | 820 | 790 | +30 | 721 | 733 | −12 | 718 | 760 | −42 |
| 13. | 1/28/51 | 792 | 773 | +19 | 699 | 720 | −21 | 660 | 725 | −65 |
| 14. | 3/23/57 | 779 | 799 | −20 | 806 | 754 | +52 | 791 | 792 | −1 |
| 15. | 2/15/57 | 870 | 784 | +86 | 746 | 695 | +51 | 722 | 733 | −11 |

# APPENDIX IV

## Test data; height anomalies for 15 cases of non-blocks, miscellaneous areas

## F-6

| Case # | Date | $Z_{A_6}$ | $\overline{Z}_{A_6}$ | $z_{A_6}$ | $Z_{B_6}$ | $\overline{Z}_{B_6}$ | $z_{B_6}$ | $Z_{V_6}$ | $\overline{Z}_{V_6}$ | $z_{V_6}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/10/53 | 735 | 768 | −33 | 712 | 745 | −33 | 721 | 784 | −63 |
| 2. | 2/1/57 | 885 | 779 | +106 | 888 | 764 | +124 | 800 | 770 | +30 |
| 3. | 1/11/51 | 777 | 787 | −10 | 760 | 776 | −16 | 780 | 774 | +6 |
| 4. | 1/25/52 | 702 | 783 | −81 | 643 | 769 | −126 | 792 | 777 | +15 |
| 5. | 2/5/51 | 763 | 779 | −16 | 679 | 802 | −123 | 782 | 758 | +24 |
| 6. | 3/8/57 | 737 | 788 | −51 | 808 | 799 | +9 | 734 | 780 | −46 |
| 7. | 2/19/57 | 775 | 753 | +22 | 746 | 780 | −34 | 821 | 780 | +41 |
| 8. | 2/22/51 | 810 | 772 | +38 | 823 | 785 | +38 | 744 | 775 | −31 |
| 9. | 1/10/52 | 733 | 788 | −55 | 785 | 802 | −17 | 873 | 760 | +113 |
| 10. | 3/14/57 | 812 | 770 | +42 | 700 | 749 | −49 | 843 | 793 | +50 |
| 11. | 1/1/51 | 740 | 776 | −36 | 729 | 787 | −58 | 798 | 773 | +25 |
| 12. | 2/19/51 | 705 | 782 | −77 | 701 | 786 | −85 | 658 | 733 | −75 |
| 13/ | 1/8/53 | 805 | 773 | +32 | 779 | 778 | +1 | 690 | 781 | −91 |
| 14. | 3/1/54 | 708 | 799 | −91 | 803 | 797 | +6 | 688 | 740 | −52 |
| 15. | 2/16/51 | 817 | 784 | +33 | 760 | 780 | −20 | 811 | 772 | +29 |

F-5

| Case # | Date | $Z_{C_5}$ | $\overline{Z}_{C_5}$ | $z_{C_5}$ | $Z_{Q_5}$ | $\overline{Z}_{Q_5}$ | $z_{Q_5}$ | $Z_{R_5}$ | $\overline{Z}_{R_5}$ | $z_{R_5}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/11/53 | 728 | 721 | +7 | 680 | 703 | − 23 | 680 | 729 | −49 |
| 2. | 2/2/57 | 872 | 742 | +130 | 712 | 690 | +22 | 741 | 701 | + 40 |
| 3. | 1/12/51 | 712 | 754 | − 42 | 658 | 690 | − 32 | 636 | 686 | −50 |
| 4. | 1/26/52 | 692 | 744 | − 52 | 685 | 685 | ± 0 | 690 | 693 | − 3 |
| 5. | 2/6/51 | 741 | 802 | − 61 | 710 | 729 | − 19 | 740 | 719 | + 21 |
| 6. | 3/9/57 | 840 | 809 | + 31 | 790 | 768 | + 22 | 822 | 752 | + 70 |
| 7. | 2/20/57 | 803 | 783 | + 20 | 696 | 742 | − 46 | 680 | 729 | − 49 |
| 8. | 2/23/51 | 840 | 780 | + 60 | 801 | 742 | + 59 | 740 | 708 | + 38 |
| 9. | 1/11/52 | 804 | 809 | − 5 | 757 | 731 | + 26 | 762 | 719 | + 43 |
| 10. | 3/15/57 | 635 | 728 | − 93 | 758 | 732 | + 26 | 777 | 750 | + 27 |
| 11. | 1/2/51 | 720 | 804 | + 84 | 745 | 748 | − 3 | 767 | 730 | + 37 |
| 12. | 2/20/51 | 792 | 761 | + 31 | 795 | 718 | + 77 | 773 | 716 | + 57 |
| 13. | 1/9/53 | 800 | 804 | − 4 | 691 | 767 | − 76 | 700 | 749 | − 49 |
| 14. | 3/2/54 | 858 | 776 | + 82 | 769 | 750 | + 19 | 759 | 743 | + 16 |
| 15. | 2/17/51 | 798 | 770 | + 28 | 702 | 701 | +1 | 675 | 690 | −15 |

F-4

| Case # | Date | $Z_{Q4}$ | $\overline{Z}_{Q4}$ | $z_{Q4}$ |
|---|---|---|---|---|
| 1. | 1/12/53 | 642 | 703 | − 61 |
| 2. | 2/3/57 | 756 | 690 | + 66 |
| 3. | 1/13/51 | 640 | 690 | − 50 |
| 4. | 1/27/52 | 690 | 685 | + 5 |
| 5. | 2/7/51 | 800 | 729 | + 71 |
| 6. | 3/10/57 | 810 | 768 | + 52 |
| 7. | 2/21/57 | 763 | 742 | + 21 |
| 8. | 2/24/51 | 752 | 742 | + 10 |
| 9. | 1/12/52 | 796 | 731 | + 65 |
| 10. | 3/16/57 | 726 | 732 | − 6 |
| 11. | 1/3/51 | 775 | 748 | + 27 |
| 12. | 2/21/51 | 760 | 718 | + 42 |
| 13. | 1/10/53 | 740 | 767 | − 27 |
| 14. | 3/3/54 | 709 | 750 | − 41 |
| 15. | 2/18/51 | 701 | 701 | ± 0 |

## F-3

| Case # | Date | $Z_{A_3}$ | $\overline{Z}_{A_3}$ | $z_{A_3}$ | $Z_{S_3}$ | $\overline{Z}_{S_3}$ | $z_{S_3}$ | $Z_{T_3}$ | $\overline{Z}_{T_3}$ | $z_{T_3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1/13/53 | 704 | 768 | − 64 | 760 | 761 | −1 | 810 | 780 | + 30 |
| 2. | 2/4/57 | 839 | 779 | + 60 | 730 | 733 | −3 | 711 | 768 | −57 |
| 3. | 1/14/51 | 731 | 787 | − 56 | 750 | 715 | + 35 | 761 | 761 | ± 0 |
| 4. | 1/28/52 | 726 | 783 | − 57 | 681 | 730 | − 49 | 770 | 770 | ± 0 |
| 5. | 2/8/51 | 795 | 779 | + 16 | 641 | 730 | − 91 | 762 | 761 | + 1 |
| 6. | 3/11/57 | 820 | 788 | + 32 | 772 | 744 | + 28 | 740 | 753 | − 13 |
| 7. | 2/22/57 | 768 | 753 | + 15 | 698 | 701 | − 3 | 669 | 693 | − 30 |
| 8. | 2/25/51 | 751 | 772 | − 21 | 720 | 690 | + 30 | 720 | 701 | + 19 |
| 9. | 1/13/52 | 841 | 788 | + 53 | 746 | 721 | + 25 | 757 | 753 | + 4 |
| 10. | 3/17/57 | 736 | 770 | − 34 | 800 | 780 | + 20 | 772 | 796 | − 24 |
| 11. | 1/4/51 | 824 | 776 | + 48 | 703 | 719 | − 16 | 701 | 737 | − 36 |
| 12. | 2/22/51 | 726 | 782 | − 56 | 782 | 727 | + 55 | 812 | 765 | + 47 |
| 13. | 1/11/53 | 775 | 773 | + 2 | 801 | 720 | + 81 | 720 | 725 | − 5 |
| 14. | 3/4/54 | 677 | 799 | − 122 | 772 | 754 | + 18 | 829 | 792 | + 37 |
| 15. | 2/19/51 | 763 | 784 | − 21 | 722 | 695 | + 27 | 740 | 733 | + 13 |

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